Nano-enabled Technology and Security: Hype, Hope and Prey

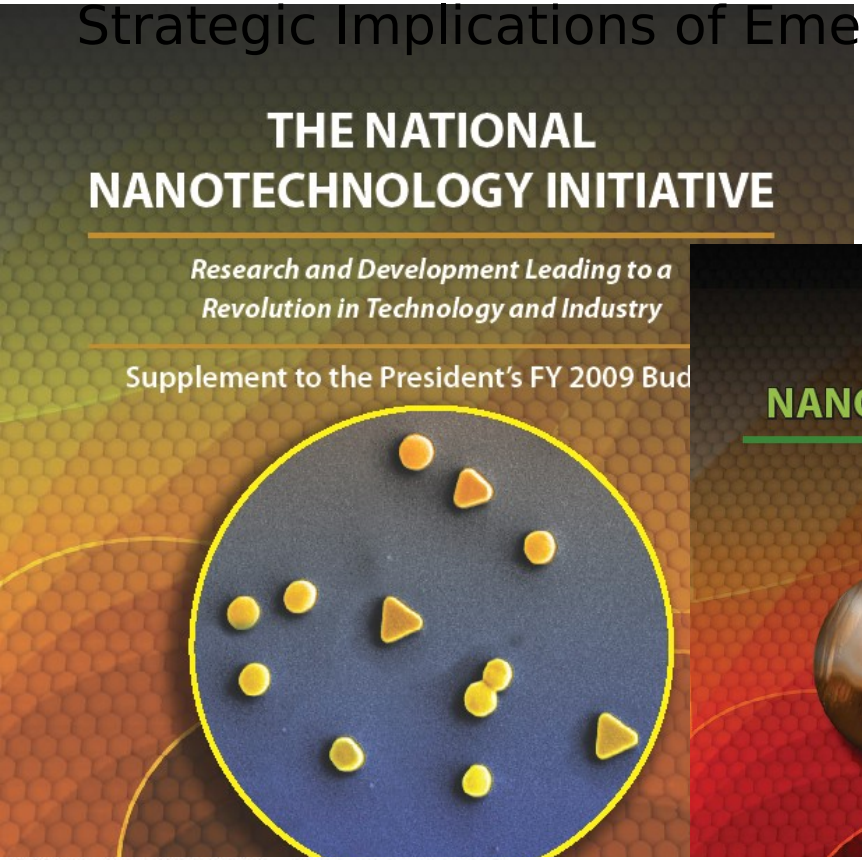
Strategic Implications of Emerging Technologies 14-16 Apr 2009

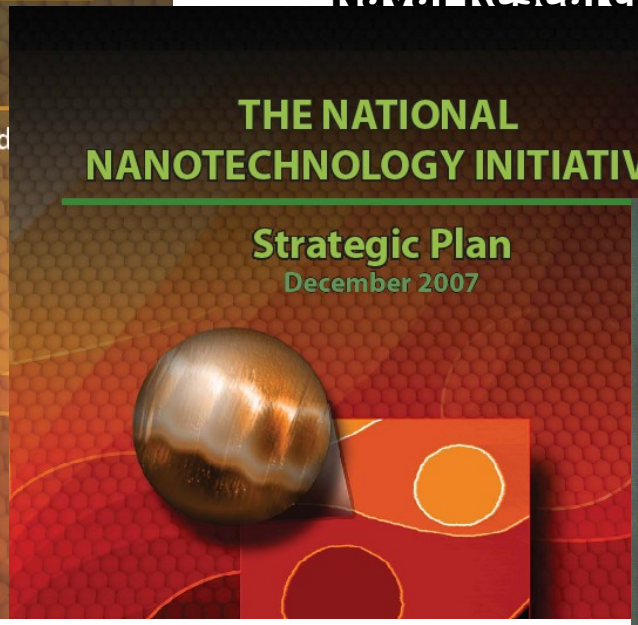
Dr. James S. Murday

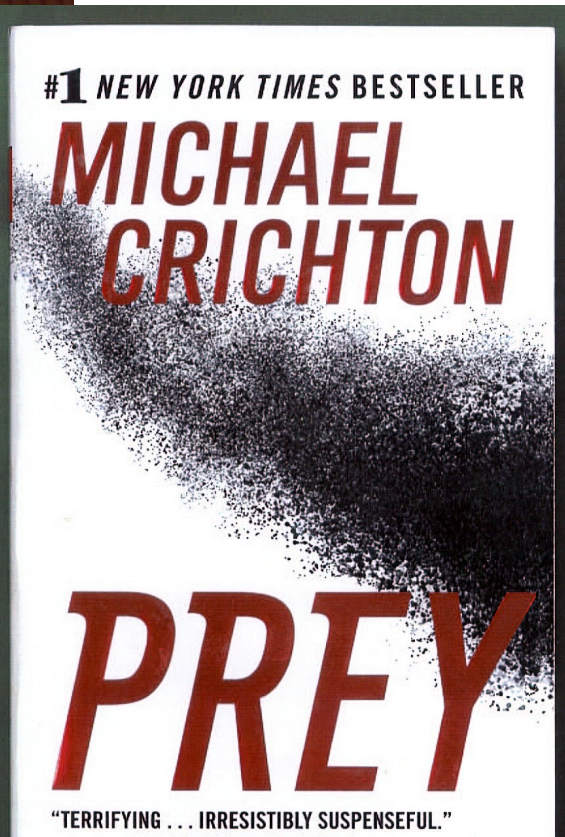
University of Southern California

Naval Research Laboratory and

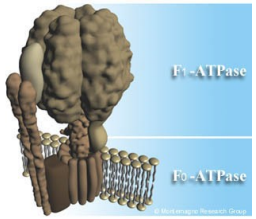
nano.gov

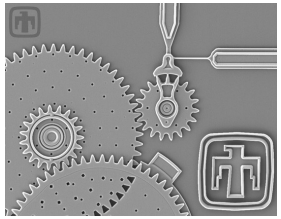


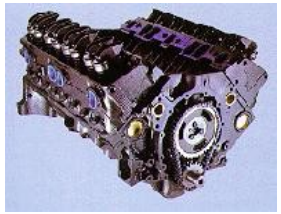




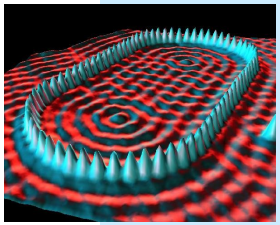
NANOMETER (nm) SCALE SCIENCE AND TECHNO

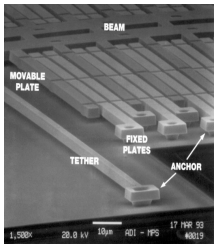






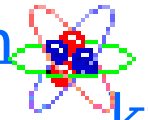
MAT - TECH

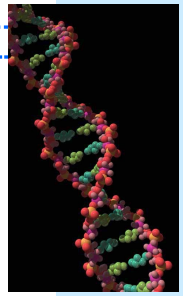


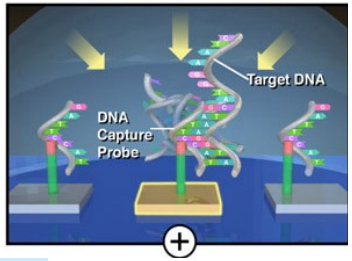


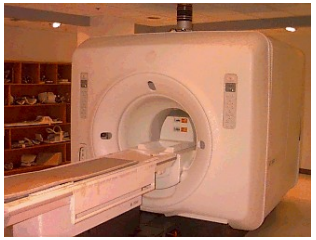
INFO - TECH

pm nm µm mm meter

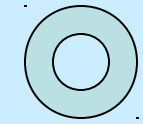


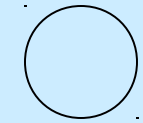


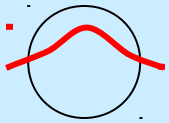




BIO - TECH







PHENOMENA	EXAMPLE
Interface/Interphase	oxide layer cell membrane
Size effects	paramagnetic limit antibody/antigen
recognition	
Quantum confinement	QD color

The Vision and S&E Challenges

Nanomaterials by Design

Opportunities/Challenges in Bio/Chem/Engn/Materials/Physics

~1750 - 2000

Old (atomic) World

Building Blocks:

109 Elements (→ molecules →)

Assembly Rules:

Periodic Table Groupings
Ionic Bonds
Covalent Bonds
"Metallic" Bonds

Guidance:

Atomistic or Continuum Models explain experiment

2000 - 2025 ?

Transition (nano)

Dendritic
Quantum Dots
Nanoclay
Superlattices

Colloidial
Devices
Block Copolymer
Metamaterials
Biomimetic
Atomic Layer Epi

Multisize-Scale Supercomputer

2025 ?

New (multi-scale) World

Building Blocks:

Effectively unlimited variety of quality
dots, clusters, macromolecules
wires, tubes
films

Assembly Rules:

Atomic bonding, plus
Van-der-Waal forces
Coulomb forces
Magnetic forces
Molecular recognition
Steric hindrance
Fluid drag

Guidance:

Predict Composition/Structure to get the Desired Property

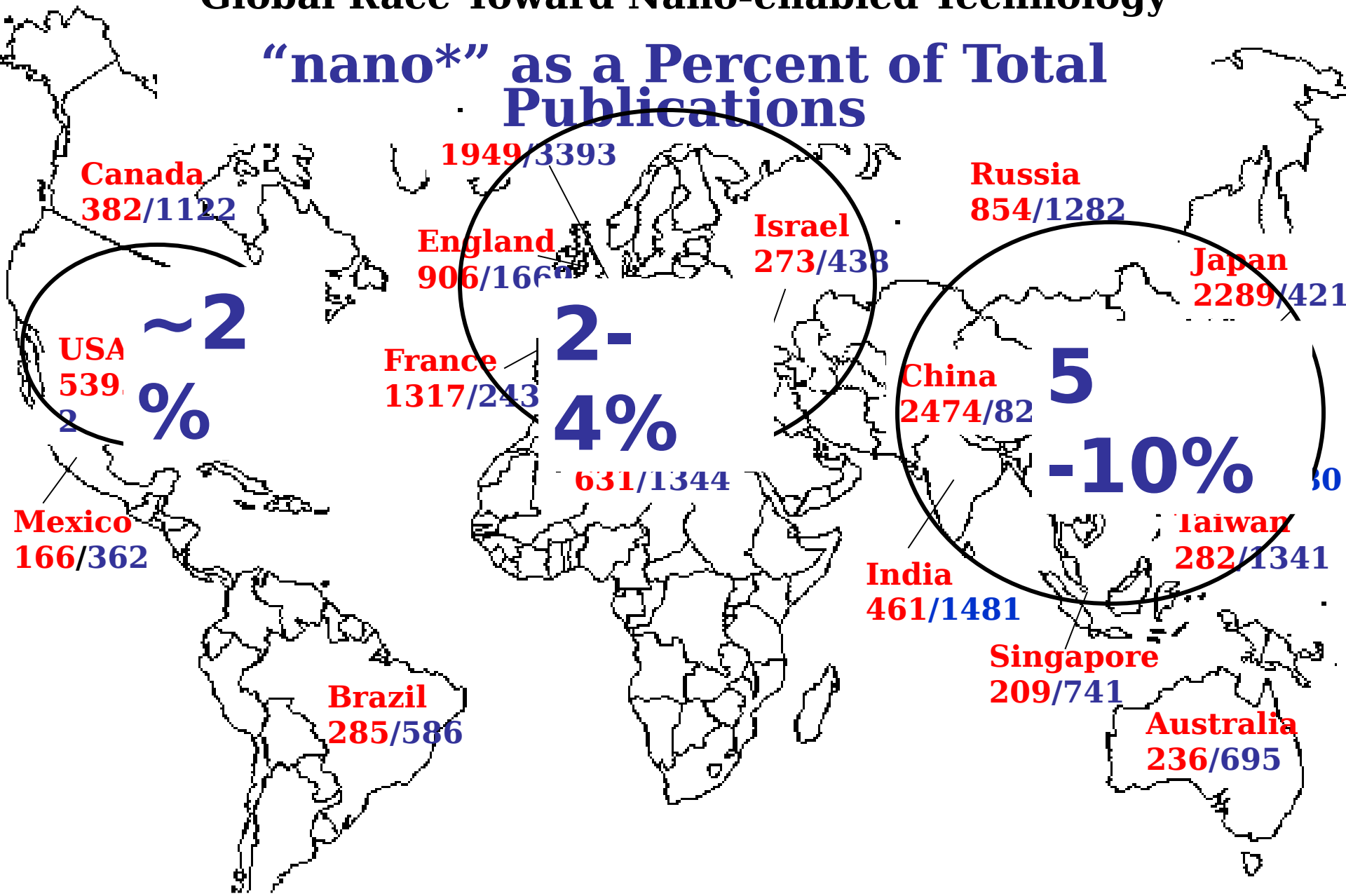
Biological Existence Proof of

Complex, Highly Functional, Directed, Hierarchical, Assembled Systems

	Human: Self Assembly	Automobile: Assembly Line
	One 150 lb functioning unit	One 5000 lb functioning unit
Manufacturing		
Feedstocks		
Fluids	**~ 5,000 lb** water (1 lb/day x 15 yr)	**~ 10,000 lb** water (cooling)
Solids	**~ 5,000 lb** organics (1 lb/day x 15 yr)	**~ 5,000 lb** metal/plastic/ceramics
Waste streams	**~ 10,000 lbs** (2 lb/day x 15 yr)	**~ 50 lbs** (solids)
Energy	**~ 10^9 gm-cal** (1000 cal/day x 15 yr)	**~ 10^9 gm-cal**
Timescale	**~ 100,000 hours**	**~ 25 hours**
Manpower required	**~ 10 PY (parental)**	**~ 0.1 PY**
Return on Investment	self replicating, sentient (??) worker	smart transport
	~ 10^{15} bit memory (synapses)	~ 10^8 bit memory

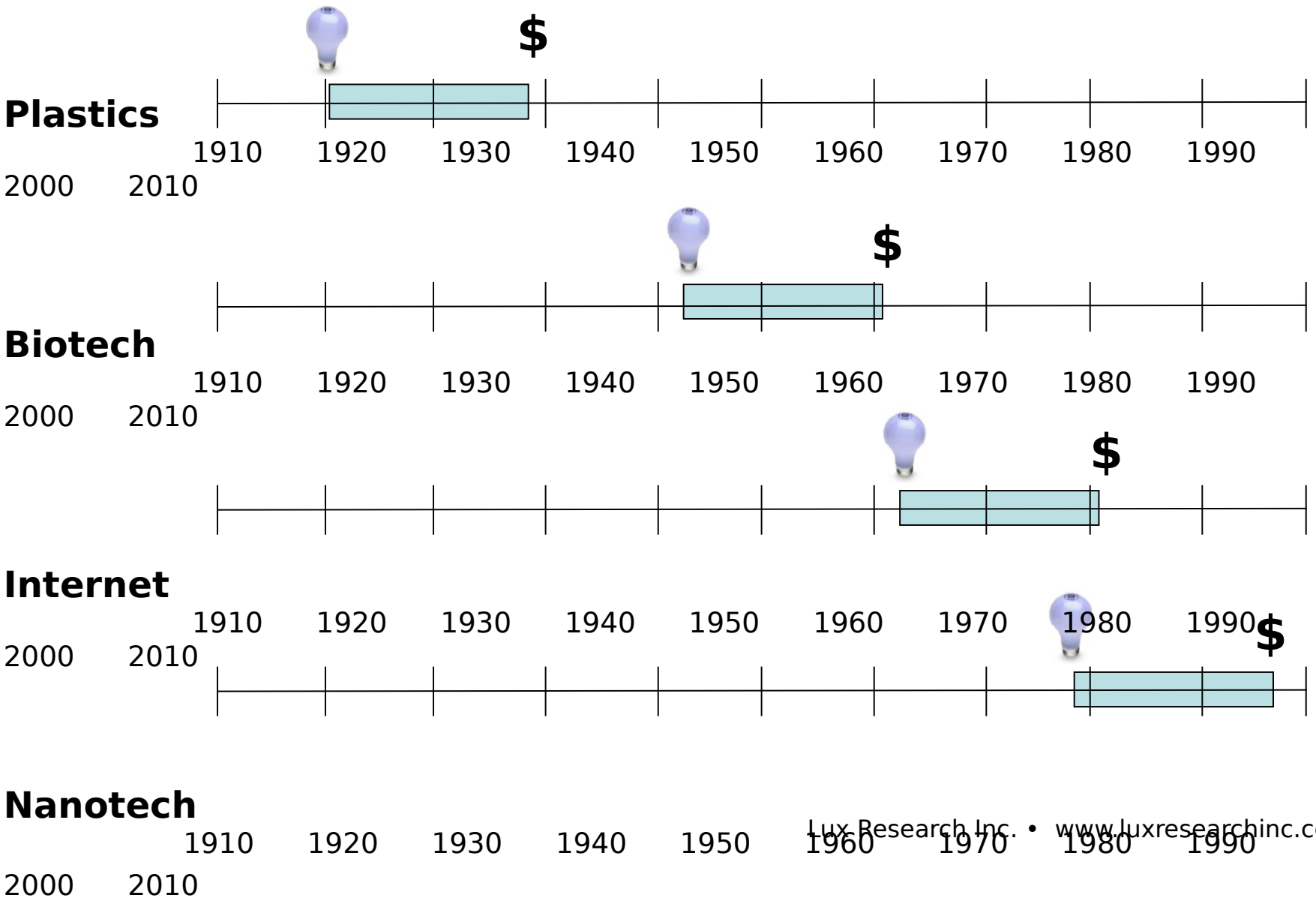
But challenging speed / waste / reliability obstacles for General Manufacturing

Global Race Toward Nano-enabled Technology



Worldwide CY2002/06/08 Publication Counts – 18,539 / 43,225 /

Nanotechnology fits a commercialization pattern



Anticipated DOD Impact of Nano-enabled Technology

By Warfighting Category

- **Weapons of Mass Destruction**
- **Warfighter**
- **Platforms**
- **Weapons**
- **Information Dominance**

Weapons of Mass Destruction - CBRNE

Why Nano

- **Improved detector sensitivities – signal to noise**
- **Miniaturized arrays for selectivity**
- **Tailored high surface area materials**
- **Selective catalysts**
- **Abiotic / Biotic interface – electrons vice ions / molecular shape**

Function

- **Microfabricated sensor suites – Laboratory on a Chip**
- **Fabrics / Adsorbers for protective g**
- **Decontamination nanostructures / c**
- **Protective paints and coatings**

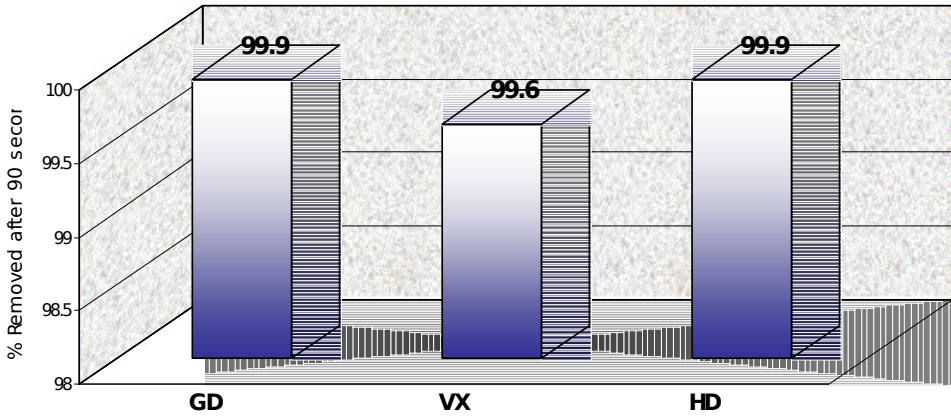
Defense / Homeland Security Appli

- **Linked, unattended site monitors**
- **MOPP gear**
- **Collective-protection shelters**
- **Decontamination**

Nanostructured Decontamination

Non-toxic nanomaterials demonstrated to treat a wide range of toxic chemicals and CW agents

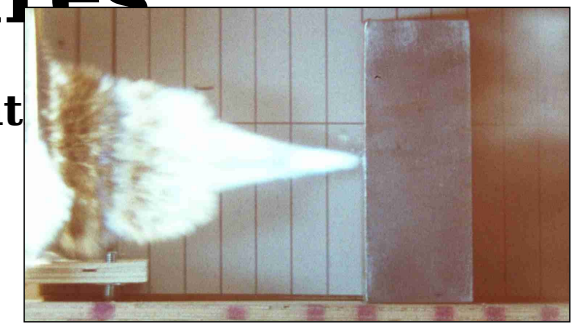
- High surface area - greater capacity and faster reactivity for increased protection
- Proven to remove over 99.6% of VX, GD (soman) and HD (mustard gas) in <90 sec; converting these agents to safer by-products
- System of pressurized cylinders, bulk pails and shakers offers robust utility against range of scenarios with minimal training
- Fielded in July 2004 by RDECOM
- Joint effort between ARL-ARO, Kansas State University, NanoScale Materials, Inc., USSOCOM, USMC, and DTRA



Weapons / Countermeasures

Why Nano

- Control of energy release – short diffusion pat
- Grain boundary effects – mechanics
- Lower scattering in visible/IR
- Design flexibility – nanocomposites



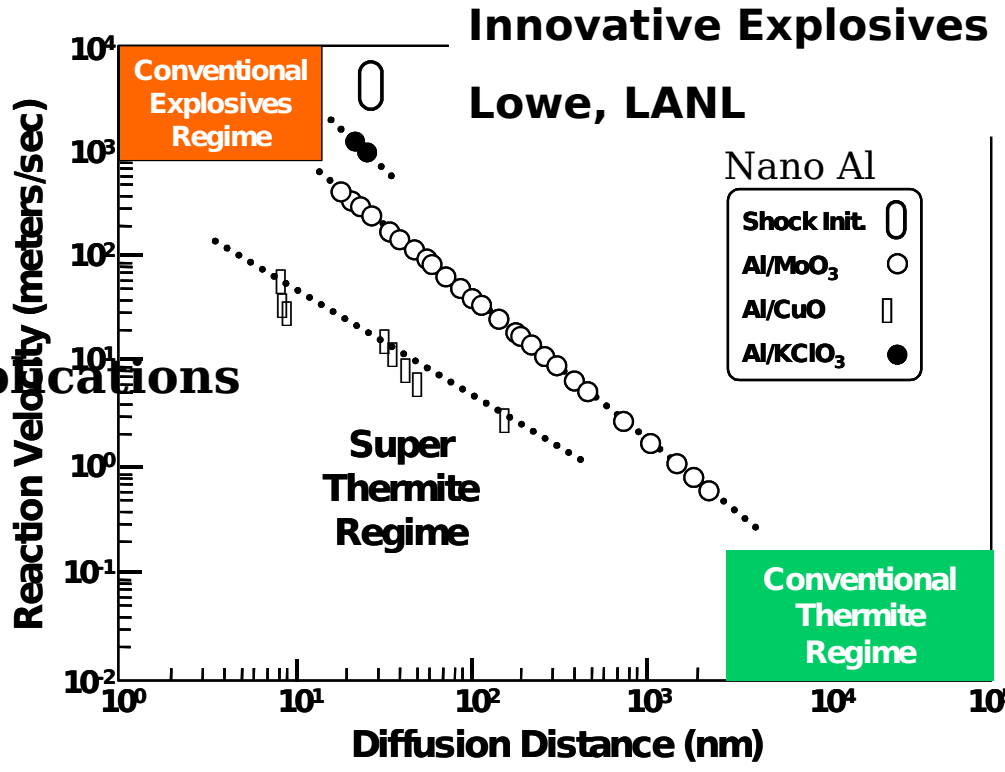
Non-U Penetrators

Function

- Tailored reaction rate control
- Shaped ceramic materials
- IR/Vis transparent substrates
- Nanostructures in physiology

Defense / Homeland Security Applications

- High power IR lasers
- Missile seeker domes
- EO / IR countermeasures
- Non-lethal weapons
- Insensitive, tailored explosives



Flow of Requirements
Precision Attack & Force Projection

System-Level Capabilities

More Energy on Target

Technical challenges

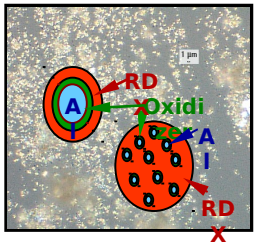
Controlled, High-Power Explosives

Miniature Lethal Packages

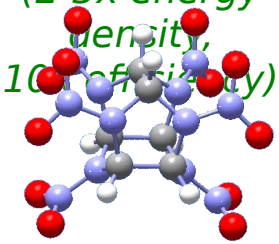
Directed Energy Weapons

NST R&D Areas

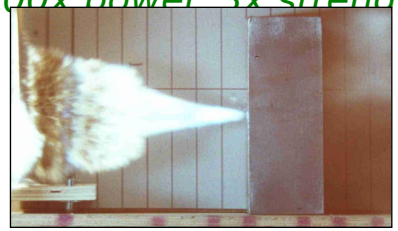
Nano-structured explosives
(100x power)



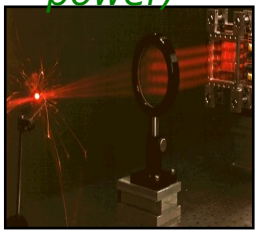
Nanoengineered high-energy-density materials
(2-3x energy density, 10x efficiency)

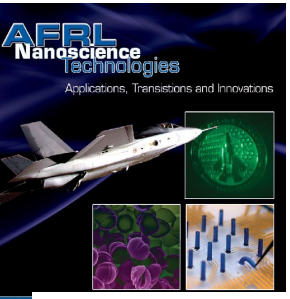


Reactive nanocomposites for high-speed penetrators
(100x power, 3x strength)



Nanostructured lasers & HPMW emitters
(10x efficiency, power)





Warfighter

Why Nano

- More function per unit weight / volume
- Lower electrical power (per function)
- High surface area, tailored particles/fibrils
- More efficient charge separation/diffusion
- Biotic/abiotic interface
- Multi-functional structures – mechanical, optoelectron

…

Function

- Monitor and modify body physiology
- Body Armor – augmented Kevlar / Ceramic tile
- Active camouflage
- Energy conversion - battery / fuel cell / solar cell / piez
- Information from data
- Preparation and preservation of food / wate

Defense / Homeland Security Applications

- Personal decision aides
- Warfighter uniform / MOPP gear / Body arm
- Man portable power
- Weapon automation
- Therapeutics / Prosthetics

HP iPAQ Mobile Messenger
WiFi, Bluetooth, GPS, Camera, Pocket PC

Warrior

Conformal Antenna Materials
- Electroceramics

Lightweight Ballistic Helmet
- Carbon Nanotubes
- Nanofibers
- Nanoparticulates

Compact Power Sources
- Fuel Cell Membranes

Ballistic Face Shield
- Polymer Layered Silicates
- Multilayered Polymers

Chemical/Biological Protective Clothing
- Nanofibers
- Perm-Selective Membranes
- Nanoreactor Coatings

Advanced Weaponry
- Nanoenergetics
- Nanocomposite Primers- MICs
- Nanometallics
- Lightweight Cartridge Casings

Chemical/Biological Handheld Sensors
- Chemical/Biological Detection (Dendrimers)
- Water Quality (Molecularly Imprinted Polymers)

Chemical/Biological Skin Protectant Creams
- Nanoreactors

Potable Water
- Nanoencapsulants
- Membrane Nanofilters

Information Dominance

Why Nano

- Lower power per process – less dissipation per process (but more per chip)
- Better signal transduction – signal to noise im
- Higher processing speed – shorter transit tim
- Higher function density
- Couple photonics/electronics - plasmons

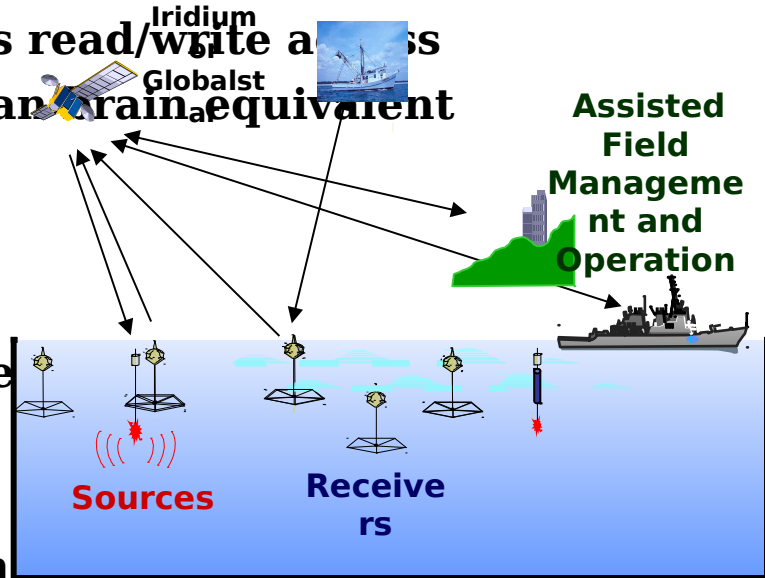
Stan Williams, H

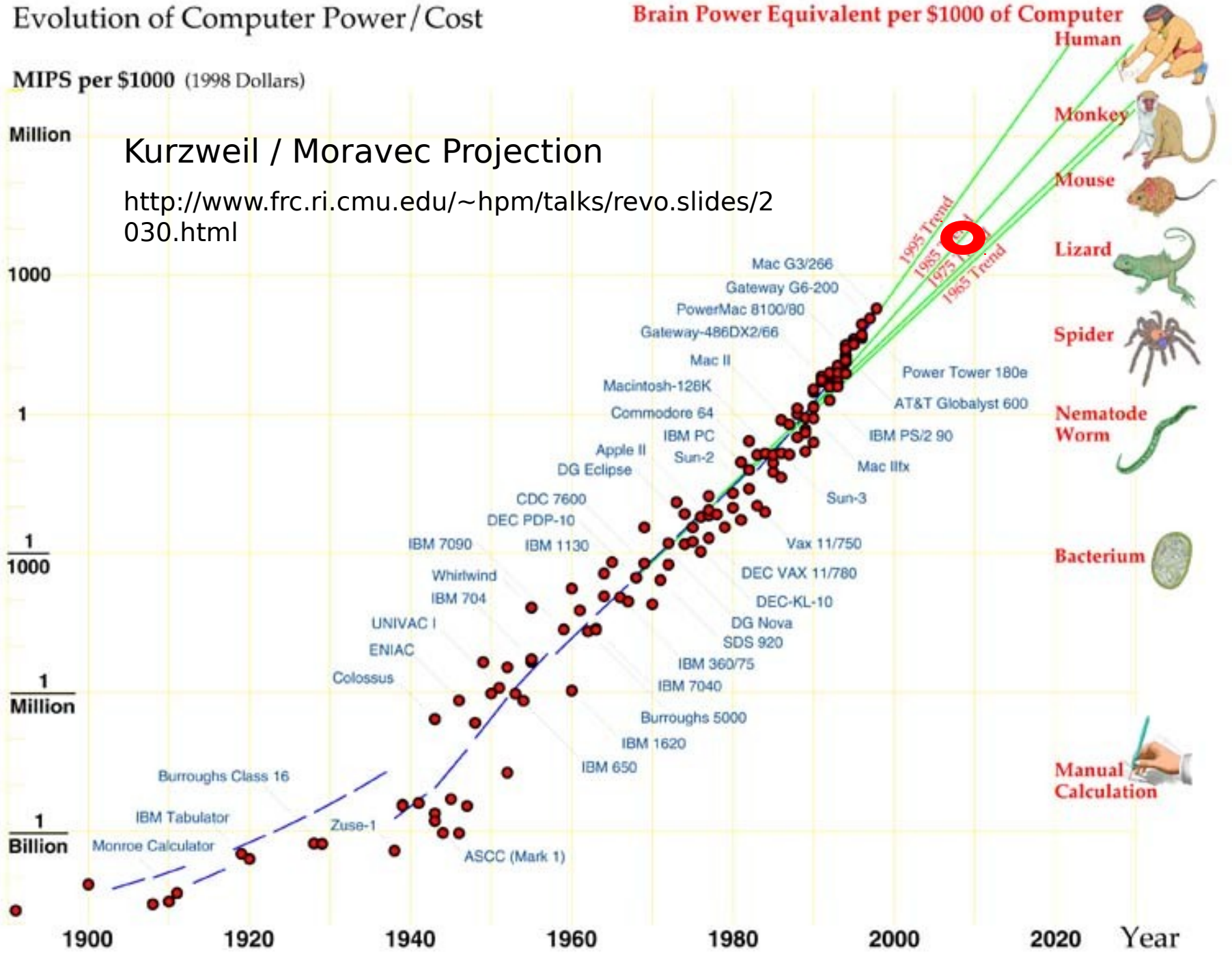
Function

- Microfabricated sensor arrays
- Flexible, paper thin, solid-state emissive displ
- Emitters/Detectors in terahertz spectral range
- Nonvolatile terabit/cm² data density with ns read/write a ss
- Memory / Processor device density at human brain equivalent

Defense / Homeland Security Applications

- Network centric
- Automation / robotics for reduced manpowe
- Effective training through virtual reality
- Individual warfighter decision aides
- Uninhabited combat vehicles (fighter, subm




Evolution of Computer Power / Cost
MIPS per $1000 (1998 Dollars)
Million
1000
1
1/1000
1/Million
1/Billion
Kurzweil / Moravec Projection
http://www.frc.ri.cmu.edu/~hpm/talks/revo.slides/2030.html
Brain Power Equivalent per $1000 of Computer
Human
Monkey
Mouse
Lizard
Spider
Nematode Worm
Bacterium
Manual Calculation
1995 Trend
1955 Trend
Mac G3/266
Gateway G6-200
PowerMac 8100/80
Gateway-486DX2/66
Mac II
Macintosh-128K
Commodore 64
IBM PC
Apple II
Sun-2
DG Eclipse
CDC 7600
DEC PDP-10
IBM 7090
IBM 1130
Whirlwind
IBM 704
UNIVAC I
ENIAC
Colossus
IBM 1620
IBM 650
Burroughs Class 16
IBM Tabulator
Monroe Calculator
Zuse-1
ASCC (Mark 1)
Power Tower 180e
AT&T Globalyst 600
IBM PS/2 90
Mac IIfx
Sun-3
Vax 11/750
DEC VAX 11/780
DEC-KL-10
DG Nova
SDS 920
IBM 360/75
IBM 7040
Burroughs 5000
1900
1920
1940
1960
1980
2000
2020
Year

Platforms

Why Nano

- **Design flexibility - multifunctional, adaptive**
- **Inhibit nanoscale failure initiators**
- **Controlled energy release - propulsion**
- **Negative index refraction IR/Vis**

Die Another Day – invisible car

Function

- **High strength-to-weight, fire resistant composites**
- **Smart materials – sense / respond**
- **Multispectral index of refraction change**
- **Energy efficient fuels / propellants**

Defense / Homeland Security Appli

- **Automation for Reduced Manning**
- **Higher performance**
  - **(e.g., hi-g maneuver, greater r**
- **Low observable**
- **Low maintenance**

Grumman X-47

Boeing X-45

MCM Main Propulsion Shafts

- Problem: Debris trapped in the staves grind the shafts
  - Shaft life limited to ~1 yr
  - No existing coating was available which could
    - Survive in the environment
    - Protect the shaft
    - Not create galvanic corrosion problems
- Solution: Development of a revolutionary ceramic nanocomposite coating
- Status:
  - Coated shafts tested in service on four ships
  - Inspection after eight years shows no visible damage

Without coating; one year service

With coating after 8 years of service

Kabacoff, ONR and Scandell, NSWCCSD

Potential Nano-enabled Game Changers

Information Technology – Moore's Law continued

- Functional equivalent of human brain for less than $1K
- Non-volatile, radiation hard, terabit/cm^2, nanosecond access data storage
- Integrated electrical/electro-optical signal processing chips
- Conformable, reasonably high capability, inexpensive information processing

Warfighter

- Medical therapeutics / prosthetics / real-time physiology sensing
- Biotic/abiotic enabled performance modification – Kurzweil Singularity?
- Individual human genome for under $1K – manpower selection
- Virtual reality training
- Man-portable energy sources – solar, fuel cell, battery, capacitor, piezotronics

High Performance Unattended Combat Platforms - Robotics

- Lighter weight / higher strength, smart materials
- Improved reliability (reduced corrosion, friction, wear,…)
- Multispectral signature control / obscuration (??)
- Energy efficiencies

Weapons

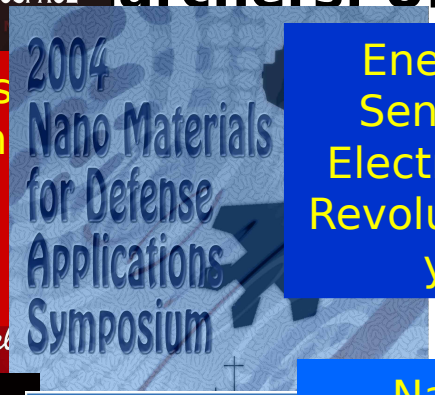
- Manipulation of brain functions
- Higher performance materials; Control of energy release rates

NanoTechnology for Defense Conferences

Objective: Bridge the gap between revolutionary nanoscience for materials and DoD applications, needs and drivers

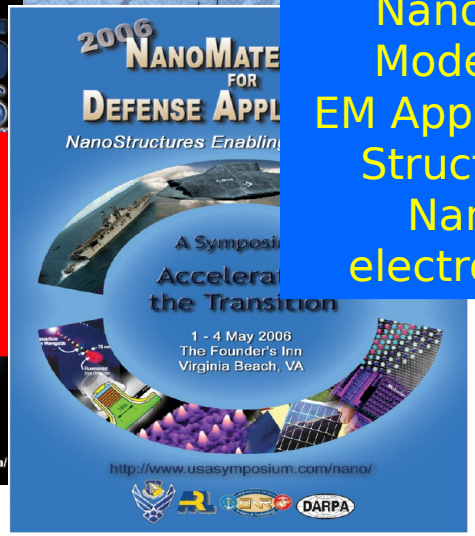
Participants: Industry system integrators and researchers, DOD m and S&T program officers, DOD/National Lab earchers. University PIs; SBIR/STTR PIs

NanoEnergetics
Adv. Propulsion
Directed Energy
Revolutionary



Energy
Sensors
Electronics
Revolutionar
y

Bulk NanoMat.
Coatings
NanoManuf.
Revolutionary



Nano-bio
Modeling
EM Application
Structures
Nano-
electronics

http://www.usasymposium.com/na

References Relevant to Nanotechnology Impact on DOD and Homeland Security

DOD documents

"DOD Researchers Provide a Look Inside Nanotechnology", AMPTIAC Quarterly Vol 6, No 1, Spring 2002. (http://ammtiac.alionscience.com/pdf/AMPQ6_1.pdf)

DOD Strategic Basic Research Plan 2008 http://www.dod.mil/ddre/doc/Strategic_Plan_Final.pdf

Defense Nanotechnology Research and Development Programs, May 2007, report to Congress by Department of Defense, Director, Defense Research and Engineering http://www.nano.gov/html/res/pdf/DefenseNano2007.pdf

AFRL NanoScience Technologies: Applications, Transitions and Innovations www.afrl.af.mil

Books and Journal articles

"Science and Technology of Nanostructures in the Department of Defense" J.S. Murday, Journal of Nanoparticle Research **1**, 501-505 (1999).

"Implications of Emerging Micro and Nanotechnologies," Air Force Science and Technology Board, National Academy of Sciences, December 30, 2002, ISBN-10: 0-309-08623-X

Nanotechnology and Homeland Security, Daniel Ratner and Mark Ratner (Prentice Hall, 2004) ISBN 0-13-145307-6

"Defense Applications of Nanomaterials", A.W. Miziolek, S.P. Karna, J.M. Mauro and R.A. Vaia, Eds, (ACS Symposium Series 89, 2004) ISBN 0-8412-3806-7

"A Matter of Size: Triennial Review of the National Nanotechnology Initiative," 2006. National Academies Press, ISBN 0-309-10223-5

NNI documents (http://nano.gov)

National Nanotechnology Initiative – Research and Development Supporting the Next Industrial Revolution: Supplement to the President's FY2009 Budget

NNI Strategic Plan, December 2007

The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel, President's Council of Advisors on Science and Technology (PCAST), May 2005

Various workshop reports under "resources" at website: nano.gov

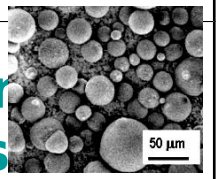
Other

Navy Working Group on Disruptive Technologies

Near Term CARTECH Nanotechnology Applicatio

Chemical & Bi
cal Agent Se

Solid State
g



Alumina-Titan
Nanocompos
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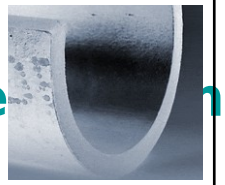
High-strengt
l Alloys



Chromium Re
ent Coatings

- CARTECH, SURTECH, SUBTECH, ATRB
- Contacted Nanotechnology leads at the National Nanotechnology Initiative, OSD, ONR, NRL, Rice University, Sandia, ORNL and AFRL
  - Socialized carrier capability needs
  - Identified potential near- and far-term nanotechnology solutions
- Naval Nanotechnology Working Group
  "Naval Investment Strategy and Recommendations in Nanoscience/Nanotechnology" – NSWCCD-TR-2005/06 (Feb 2005)

TECH ALERT

First TECH Summit focuses on Nanotechnology

The inaugural Technology Summit for SUBTECH, SURFTECH, CARTECH, and the Advanced Technology Review Board (ATRB) was held on 18 November 2004 at Systems Planning and Analysis, Inc. in Alexandria, VA. The four Navy technology insertion groups, collectively known as "the TECHs," met to discuss

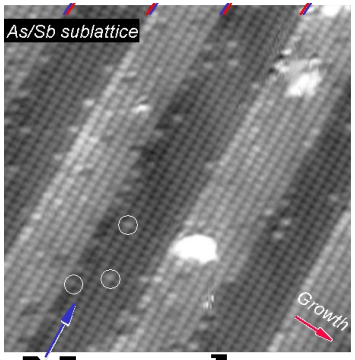
Paleontology of Nanostructures

EMPIRIC

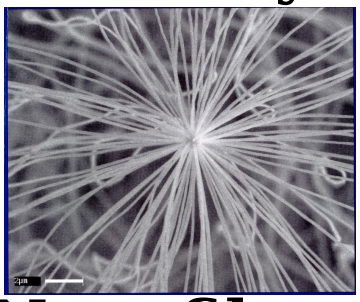
1970

SURFACE

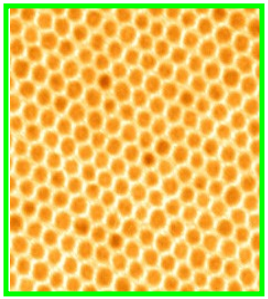
1990

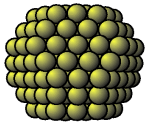


Nanolayers



Nanofilaments





Nanodots

NANO REVOLUTION?

$1T / year nano-enabled products by 2015 as a start?

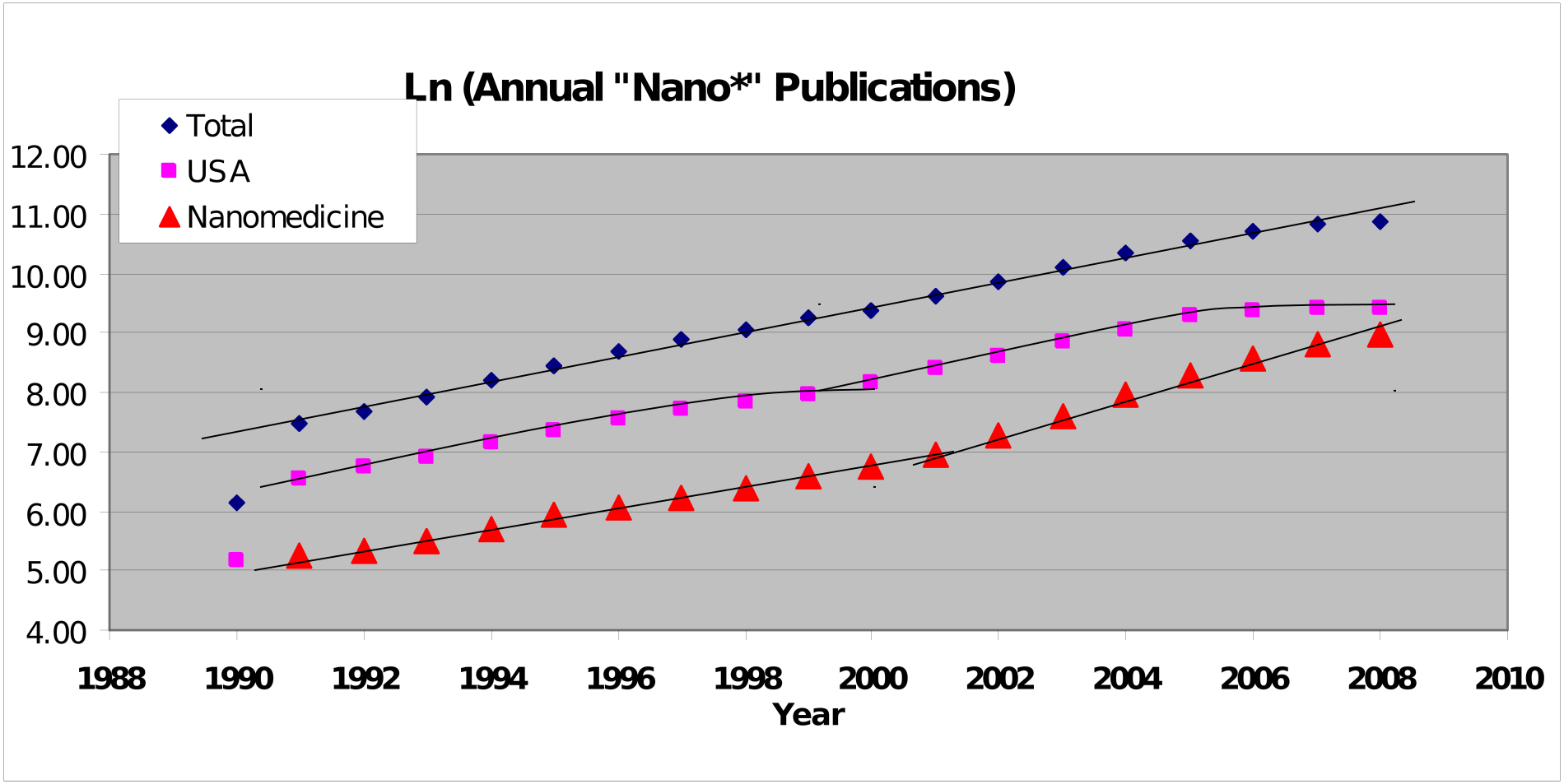
Key Challenges:

- **Directed Self-Assembly**
- **Molecular (nanoscale) Biology**
- **Biotic / Abiotic interfaces**
- **Multi-scale Modeling**
- **Standards / Quality Control**
- **Environment/Health/Safety**
- **Manufacturing**

Potential Nanomedicine

Nano-Enhanced Therapeutics:		Benefits
Targeted delivery	→	Customized to patient, fewer side effects, engineered to slip through blood-brain barrier, mucus or other obstacles
More therapeutic options	→	Expanded options for administration, such as nasal, dermal, oral, ocular
Combined detection & treatment	→	Seek-and-destroy therapy, followed by inside-the-body monitoring of patient response
Nano-Imaging and Diagnostics:		
Greater specificity	→	See and analyze at the level of individual cells
Earlier detection	→	Increases odds for effective treatment – before tumors metastasize
Less invasive	→	But yielding more definitive results
Faster, simpler	→	More options for rapid, point-of-care diagnostics
Nano-Enabled Regenerative Medicine:	→	Materials based on natural systems reduce risk of rejection
Greater biocompatibility	→	
Synthetic extracellular matrix	→	Stimulate body to regenerate damaged tissue/organ
Systems Biology	→	Predictive models for customized personal medicine

Adapted from NanoFrontiers: WW Center


Ln (Annual "Nano*" Publications)
Total
USA
Nanomedicine
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
Year

DOD STRATEGIC RESEARCH AREA: NANOSCIENCE

OPPORTUNITIES FOR MAJOR IMPACT

NANOELECTRONICS/PHOTONICS/MAGNETICS

- Network Centric Warfare
- Information Warfare
- Uninhabited Combat Vehicles
- Automation/Robotics for Reduced Manni
- Effective Training Through Virtual Realit
- Rapid Digital Signal Processing and LPI

NANOMATERIALS “BY DESIGN”

- High Performance, Affordable Materials
- Multifunction, Adaptive (Smart) Materia
- Energetic Materials
- Power Storage/Generation Materials
- Nanoengineered Functional Materials

als)

- Reduced Maintenance - halt nanoscale

failure initiation

BIONANOTECHNOLOGY - WARFIGHTER PROTECTION

PDA
- TOUCH SCREEN
- GPS
- RFID READER
- GPRS / UMTS /
- HR CAMERA
- WIRELESS RF
- MICRO RADAR
- IR CAMERA
- TELEWEAPON
- ENCRYPTED DATA

EVENT DRIVEN IFO
NEC NETWORK

BODY AREA NETWORK

WEAPON
- RFID TAG
- IR CAMERA

ELECTRONIC BC SHOE NOSE

WIRELESS SOLDIER

TNO Nanotechnology

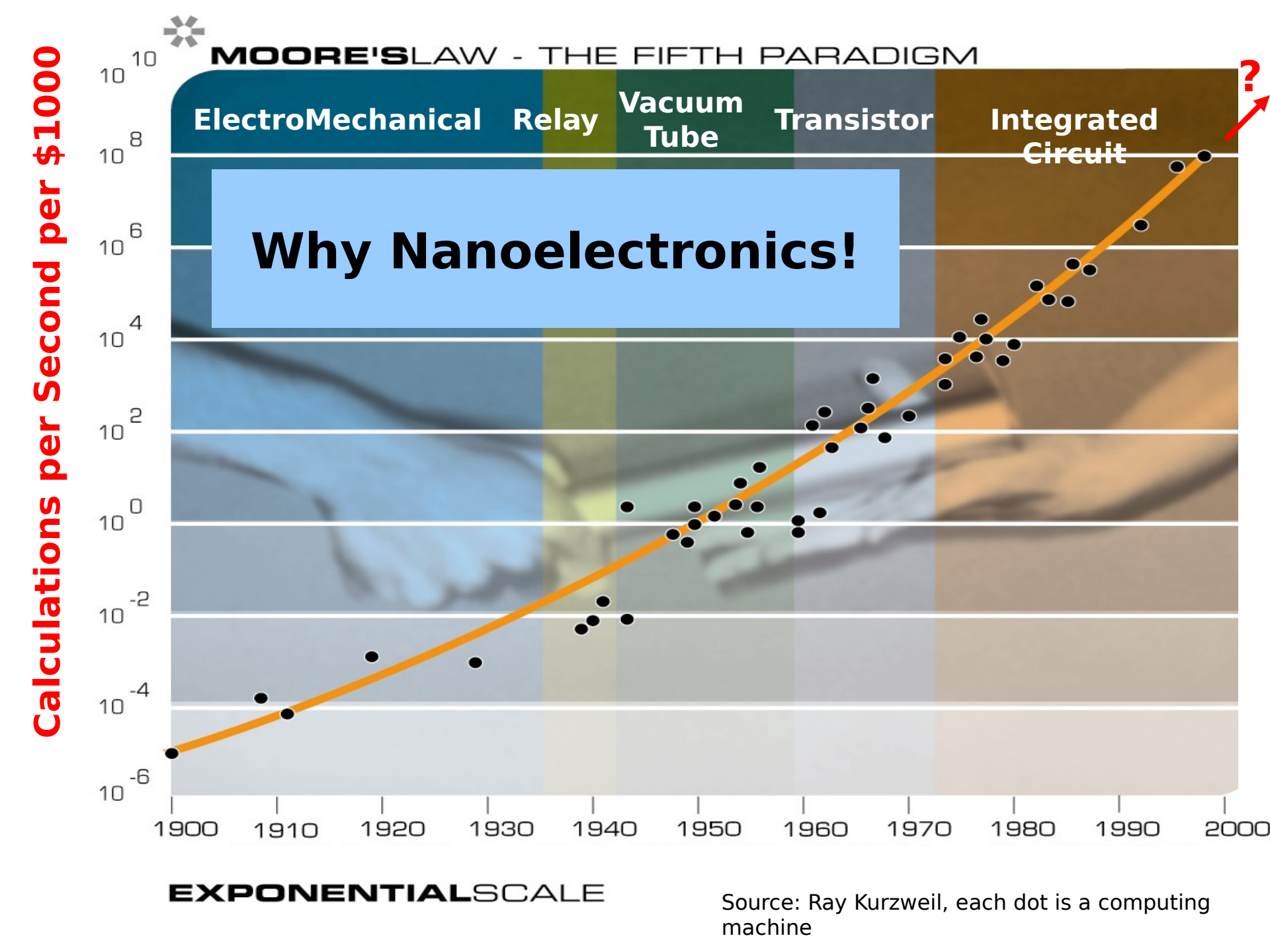
HELMET
-GPS
- 360 °CAMERA
- VISOR DISPLAY (INCL. TELEWEAPON)

WIRELESS EARPLUG
-AUDIO INFO
-T-SENSOR

WATCH
- ID
- GPS
- TIME
- TELEPHONE
- HEART RATE
- WIRELESS RF
- POSITION / MOTION
- MEMS GYRO
- DRUG DELIVERY
- CONDITION
  - HYDRATATION
  - GLUCOSE
  - LACTATE
  - MEDICAL STATUS

AMMO CARTRIDGE
WITH RFID

SENSOR NODES
- ACOUSTIC
- CHEMICAL / BIO
- IR
- RADAR
- CAMERA
- RF SWITCHED MINES
- TARGET RECOGNITION



Source: Ray Kurzweil, each dot is a computing machine

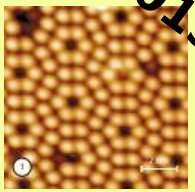
Measure | **Manipulate** | **Programs** | **Professional**

Product

1980

STM

2015



1985

AFM

1990

µContact Print

10nm NSOM

Dip Pen
Nano Imprint

1995

Aberration
Corrected TEM

nContact Print

2000

2005

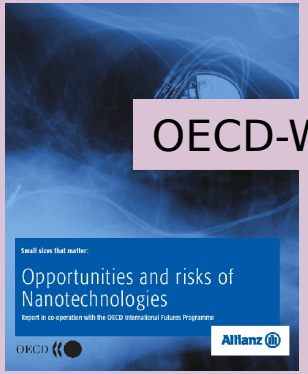
2010

US-Ultra-
submicron
Electronics

UK-Link
JP-Atomcraft

DE-Centers of
Competence

US-NNI



OECD-WG

ISO TC
229

STM
Conference

IOP
Nanotechnolog
y

AVS JVST

ACS Nano
Letters

Empiric –
catalysts,
carbon
black

Superlattices
–
laser
GMR

TPO-
Nanoclay
Composite

90nm Node
CMOS

Therapy